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THE MECHANISM OF LIGHT EMISSION

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IN THE SCIENTIFIC MONTHLY for February, 1917, Professor Guthrie gave an interesting account of the development of the electromagnetic theory of light. He explained how it had been demonstrated that light waves are very short electric waves similar in all respects except size to the electric waves used in wireless telegraphy. The latter are emitted from conductors of finite size in which electric charges oscillate, and may be several miles in length; the former are radiated from small negatively charged particles called electrons vibrating in molecules or atoms, and are measured in millionths of a millimeter. So far as the theory of light transmission is concerned, there is reason to believe that our knowledge has approached finality. There seems to be no acceptable alternative to the conclusion that light is due to wave motion in the hypothetical medium called the ether, concerning which we may never know more than we do now, but which it seems necessary to postulate as the seat of electrical and magnetic phenomena.

We may, however, hope to learn much more than we now know concerning the processes in matter which cause the radiation and absorption of light. Under the term light, we must include the invisible radiations which lie on both sides of the narrow range of frequencies or wave-lengths which are included in the visible spectrum—the short ultra-violet and X-ray radiations on one side and the longer infra-red waves, often mistakenly called heat waves, on the other. Electromagnetic theory and the effect of a magnetic field on radiating sources (the Zeeman effect) make it certain that the shorter light waves, at least, are set up by the periodic displacements of

electrons in the atom. The frequencies of vibration must be determined by the forces in the atom due to the number and arrangement of the positive and negative charges in it, hence the problem of radiation is intimately connected with that of atomic structure, and this in turn with all the properties of matter; and it is also dependent upon the relationship between matter and ether which makes possible the interchange of energy between the two. Hence the mechanism of radiation is a subject of great importance—in fact, probably the most important and the most interesting of the problems which confront the physicist to-day.

Some general facts concerning radiation are familiar to all. We know that most luminous sources are very hot—red-hot at a moderate temperature, white-hot, that is to say emitting all colors, at very high temperatures. From this we may infer that heat is the cause of radiation in such cases, and that the colors emitted depend upon the temperature. Since heat is energy of molecular motion, we might jump to the conclusion that the agitation of the molecules sends out waves in the ether just as the jumping of a trout sends out waves in water. But unfortunately such a simple explanation seems insufficient, for a high temperature is not in all cases necessary to produce luminosity. The reader may recall some familiar illustrations of light emission by sources which are not hot. Many substances phosphoresce brightly at ordinary temperatures or even at such low temperatures as that of liquid air. The glowworm emits light of colors which are not radiated by carbon or a metal until it reaches white heat. The aurora glows brightly in the atmosphere at elevations where intense cold prevails. On the other hand, air and many other gases and vapors do not emit visible radiation even when heated to the highest degree. It is evident that other causes than energetic molecular motion may cause radiation. Our next inference might be that light is due to the vibrations of atoms within molecules which may not themselves possess much translatory energy, but this hypothesis proves insufficient in the case of monatomic gases, such as helium and mercury vapor. There seemed to be no explanation possible so long as it was assumed (without any rational basis, as we now see) that the atom is indivisible and unchangeable. No progress was possible until the discovery of the electron and of the atomic disintegration characteristic of radioactive processes proved the complexity of atoms.

In general luminous sources emit waves of many different

lengths and frequencies of vibration, each frequency corresponding to a different color. In order to analyze the light into its components, which is the first step toward obtaining a definite knowledge of what takes place in the source, the use of some form of spectroscope is necessary. What follows will be made clearer by the description of a simple form of spectroscope, to recall to the reader how the light is analyzed and what is meant by the "lines" of a spectrum. The light from the source is focused on a narrow slit, through which it passes in a divergent beam. A lens placed in this beam forms an image of the slit on a screen placed at the proper distance. If a prism is introduced into the path of the light, the beam will be refracted toward the base of the prism, and the deviation will be different for each color. If only one color (frequency) is present in the light, a single refracted image of the slit, of that color, may be thrown on a screen or a photographic plate. If two or more colors are present, there will be two or more images of the slit in different positions. These slit images are known as spectral lines. If the light is white, there will be an infinite number of slit images, corresponding to the infinite number of shades of color in white light, forming a continuous spectrum. If certain colors are removed by placing color screens in the path of the light there will be gaps in the spectrum, called absorption lines, corresponding to the absent slit images. Incandescent solids all give continuous spectra, with radiations extending beyond the red, and also beyond the violet at very high temperatures. Luminous gases and vapors, however, do not usually emit all colors, but only a finite number, giving rise to a corresponding number of bright lines. A series of observations by many investigators, and finally the work of Kirchhoff and Bunsen, about 1859, resulted in the recognition of the capital fact that no two elements have the same spectrum, that is, lines corresponding to each other in number and position. This makes the spectroscope an important instrument for the identification and discovery of elements in terrestrial and celestial sources, and serves also the important purpose of giving us significant data for the study of atomic structure and the relation between matter and ether which causes the emission and absorption of radiant energy.

In 1814 Fraunhofer, an optician of Munich, observed that there are many dark lines in the spectrum of the sun. The explanation was found, but not fully grasped, by Foucault in 1849, who discovered that a pair of very close dark lines in the

solar spectrum corresponded exactly in position with two bright lines emitted by luminous sodium vapor, and that if sodium vapor is placed in the path of white light the vapor absorbs the same colors, giving rise to dark lines like those in the solar spectrum. Sodium vapor in the sun's atmosphere causes these lines. Later investigation has shown that many thousands of lines in the solar spectrum correspond in position with the bright lines emitted by a number of metallic vapors, which proves that these metals exist in the sun. Further investigation has confirmed the fact that the vapors of many elements will absorb some at least of the colors which they emit when luminous. Stokes, the English physicist, pointed out the acoustical analogy. Sound waves from a tuning fork will cause a neighboring fork of the same frequency to vibrate, but will have no effect on a fork of a different frequency, and a large number of such resonating forks would form an effective screen to the sound waves by thus absorbing their energy. This suggested the possibility of a further acoustical analogy. A tuning fork emits sounds of but one frequency (analogous to the unknown case of a luminous substance emitting but one color of light), but most musical instruments, such as pianos and organ pipes, emit simultaneously a number of sounds of different pitch. The overtones emitted by a piano wire or an organ pipe always have frequencies which are simple multiples of that of the fundamental tone. If the same were true of light sources, the wave-lengths of the lines of a given element should be simple fractions of the length of the longest wave. This is not true in any case. Some elements, such as iron or uranium, have thousands of lines, chaotically arranged, so that the emission centers not only radiate a wider range of frequencies than is emitted by a piano when its entire keyboard is struck, but none of the simple numerical relationships between the frequencies are found, as is the case with the piano. It is inconceivable that any simple body, such as the hypothetical round, smooth, hard atom of kinetic theory, could emit such a complex system of radiations. There is no escape from the assumption that the atom is a very complex body, not the ultimate indivisible unit of matter which it was once, without proper foundation, supposed to be.

The first step toward a definite theory of atomic structure which would help to explain the facts consistently was the discovery by Zeeman in 1896 of the effect of a magnetic field on a radiating source. He found that if a flame colored with

sodium is placed between the poles of a strong electromagnet, when the latter is excited each spectral line, when viewed at right angles to the field, is split into three components, which are plane-polarized. When viewed in a direction parallel to the field, each line is split into two components, which are circularly polarized in opposite directions, that is to say, the ether motion is like that of right- and left-handed vortices. H. A. Lorentz, of Leiden, pointed out that he had developed a theory which would explain this phenomenon, based on the assumption that light emission is due to vibrations or revolutions of small electrified particles in atoms. In the absence of a magnetic field the displacements would be in all directions (unpolarized) and all of the same period. In accordance with familiar electro-magnetic laws, the magnetic field will retard the motion of the particles moving in one direction, will accelerate the motion of those moving in the opposite direction, and will have no effect upon motions parallel to the field. Thus the three plane-polarized components are accounted for, and also the circular polarization of the doublet, this being merely the ether vortex motion viewed end on. Quantitative measurements showed that these particles are negatively charged and have a mass about one eighteen-hundredth that of a hydrogen atom. This identified them with the cathode corpuscles, the nature of which had been discovered by J. J. Thomson shortly before. These small particles, to which the name electron has been given, are likewise discharged from negatively charged metals when illuminated by ultra-violet light, and from incandescent metals. They are apparently constituents of all substances, and play an important rôle in many physical phenomena.

The radiation from incandescent solids is undoubtedly due to the displacements of the electrons in the atoms, but these atoms are crowded so closely together and their agitation at high temperatures is so chaotic that it is difficult to picture exactly what is going on or to account for the wide range of vibration frequencies—practically an infinite number—represented in the radiation. Spectroscopic observations show that the spectra of all incandescent solids are identical in the sense that they are continuous and that the relative intensities at different wave-lengths are the same for all sources at the same temperature. As the temperature rises the intensity increases for each wave-length, but more rapidly for the shorter waves, the limit of which creeps toward the violet as the temperature rises. All solids above absolute zero emit radiations giving a

continuous spectrum. The spectrum of a cold body, such as ice, lies entirely in the infra-red. The shortest waves emitted by a piece of red-hot carbon are red, the other colors appearing in succession as the carbon becomes white-hot. It is evident from these facts that a large proportion of the radiation from any solid source lies in the infra-red and is useless so far as illumination is concerned, and that the useful fraction increases with the temperature. From the nature of the case, it is impossible to avoid this waste in the use of any solid source. One of the great practical problems awaiting a satisfactory solution is the discovery of vapors or gases which may easily be made luminous by the electric current and which will emit radiations lying mostly in the visible spectrum. The mercury lamp is the most successful of this type so far discovered, but the disagreeable color of its light prevents its extended use. Various more or less empirical laws concerning the distribution of intensity in continuous spectra have been found, and some success has been obtained in correlating these laws with general theoretical principles. Planck has in recent years deduced the most successful formula for the distribution of energy in the spectrum of a black body, based partly on the laws of probabilities and of thermodynamics and electromagnetism, partly on the bold assumption that energy can not be radiated in a continuous stream, but only in definite units, the magnitudes of which are proportional to the frequencies of vibration, the proportionality factor being known as Planck's "wirkungsquantum *h*." He assumes that the radiation is due to atomic oscillators, the electrons, but he has not explained how these electrons can have such a wide range of frequencies or given any definite physical reason why the "energy quantum" law should hold.

In the present state of our knowledge it is hardly worth our while to discuss the radiation of solids or the quantum theory further, but in considering the simpler case of the radiation of gases and vapors we shall find that experimental facts suggest some definite conclusions which may serve as the basis of plausible theories. The first of these, which goes back to the early days of spectroscopy, relates to the nature of the emission centers of the two types of discontinuous spectra, bands and lines. In the latter the lines are generally at some distance apart and arranged irregularly, although in some of the simpler spectra groups of lines ("series") have been found which are arranged with some regularity and are connected by more or less simple mathematical relations. Bands are composed of

groups of lines, those in each group very close together and at intervals which increase regularly in going from the well-defined limit called the " head " of the band, where the lines are most intense, and closest together. It was found by Mitscherlich about 1862 that many compounds, such as calcium oxide, when made luminous by a flame or a feeble electric discharge give characteristic band spectra, hence such spectra must be due to the undissociated molecule of the compound. Very intense electric discharges will in every case cause these bands to disappear and the lines of one or both the constituents of the compound to appear. It has since been found that many elements also, such as nitrogen, iodine and carbon, give band spectra when excited by a feeble electric discharge, but line spectra with the more intense discharges which may be assumed to dissociate the molecules into their constituent atoms. From such evidence we may feel fairly certain that luminous vapors in the molecular state, whether elements or compounds, give band spectra, while emission centers in the atomic state give line spectra. Some vapors, however, which certainly have monatomic molecules, such as mercury, give band as well as line spectra, so that we are compelled to look for a further ground of differentiation. The most obvious is to assume that the difference is due to the electrical state of the particle. For example, it may be that band spectra are characteristic of uncharged molecules, whether monatomic or polyatomic, while line spectra may be due to charged atoms, or ions, the charges arising from the loss or gain of electrons. There is direct experimental evidence which favors this view, although this evidence is sometimes ambiguous.

Lockyer was the first to call attention to the fact which is now evident to all observers that spectra are not the unchangeable things they were at first supposed to be. For example, a metal vaporized in a hot flame may have a simple spectrum containing relatively few lines in the hottest part of the flame, while in the green cone, which is not at such a high temperature, but where great chemical activity and a greater degree of ionization exists, a larger number of lines may be observed. The arc spectrum of a substance contains still other lines, while the spectrum of the spark discharge between terminals of the same metal usually contains many lines which do not appear in the arc spectrum, and some arc lines may be suppressed. In general, with changes in vapor density, pressure, temperature, or the mode of excitation, lines belonging to one group may

weaken or disappear, others may be strengthened, and new lines may appear. It is evident that significant changes take place in the emission centers, and that, since radiation is an electromagnetic process, these effects must be due to changes in the electrical condition of these centers. Lockyer advanced the revolutionary hypothesis that the energetic excitation due to very high temperature or intense electrical discharges might cause dissociation of the atoms into basic elements, but until the discovery of the electron such a hypothesis could not be reconciled with accepted views.

Some general inferences regarding the electrical state of the emission centers may be derived from familiar facts. When a feeble electric discharge is passed through some compound vapors, such as those of the halogen compounds of mercury, a band spectrum is obtained which is characteristic of the compound, so that the emission centers are certainly the molecules. At the same time the conductivity of the vapor for the electric current shows that there has been some kind of ionization, or separation into charged components, and apparently the only way that this can happen is by the splitting off of electrons from the otherwise unchanged molecules. The emission must accompany either the separation or the recombination of the electrons. Luminous vapors giving band spectra appear, from their conduct in an electric field, to be uncharged, hence we may infer that usually band spectra are emitted during the process of neutralization accompanying the return of an electron. Again, the conduct in an electric field of vapors giving line spectra indicates that they are always positively charged. Phenomena previously referred to indicate, however, that groups of lines which behave differently with changed physical conditions must be due to different types of emission centers. If the emission centers are positively charged atoms, the only possible differences would appear to be in the magnitude of the residual positive charge, due to the loss of one, two, or more electrons. Some light has recently been thrown on this subject by researches on "positive" or "canal" rays, especially by those of Stark and of J. J. Thomson. The spectrum of a gas is usually obtained by passing an electric discharge through it when it is sealed at low pressure in a "vacuum" tube. If a hole is drilled through the negative electrode (the cathode) it is found that at very low pressures a luminous beam is projected through this opening on the side opposite the positive electrode. This beam is deflected by electric and mag-

netic forces, and from the magnitude and direction of this deflection it may be determined from elementary electrical laws that the luminous particles are positively charged and that they are of the magnitude of the molecules or the atoms of the enclosed gas. It appears that the positive ions in the conducting gas are accelerated by the strong electric field near the cathode, are projected with great velocity through the hole, and by collisions with the molecules of gas on the other side are excited to luminosity and excite luminosity in the stationary gas. From Thomson's researches it appears that, with few exceptions, no molecules carry a negative charge, or more than one elementary positive charge. Very few atoms acquire a negative charge, but they may acquire several positive charges. Stark arrived at similar conclusions by a spectroscopic method, which gave definite information regarding the number of positive elementary charges carried by emission centers giving different groups of spectral lines. In some cases more than one interpretation is possible, but in general these results are in harmony with the view that band spectra are emitted by neutral molecules or atoms—line spectra by positively charged atoms; that the emission centers of arc and flame lines are singly charged atoms; that the enhanced or spark lines are due to emission centers having two or more elementary charges. Thus we find substantiation for Lockyer's early views. There can be but little doubt that differences in line spectra are due to differences in the degree of electrical dissociation.

This raises the question of the number of electrons in a given atom and the number which it can lose. The greatest number of lost electrons shown by Thomson's experiments was eight, in the case of mercury, and usually it does not exceed three. Radioactive phenomena, however, give us reason to believe that the atoms of the heavier elements at least contain many electrons and also many separable and positively charged units. Uranium, for example, by the successive explosive losses of these positive particles (alpha rays) and electrons (beta rays) passes through the stages of ionium, radium, and the successive transformation products, and probably in the end becomes lead. Thus great complexity is certainly true of the radio-elements, and it is probably true of the elements of smaller atomic weight, which are either not radioactive or else disintegrate so gently and slowly that we have not discovered the fact. It seems reasonable to assume that the atoms of all elements, except possibly hydrogen and helium, which may be the

elementary units, are complex structures built of a number of positively and negatively charged particles, the number diminishing until we get to helium, which probably has a single alpha particle nucleus, and hydrogen, which probably has a single nucleus. The problem of atomic structure is concerned with the number and relative arrangement of these particles in the atom, and the problem of radiation with the causes and nature of the disturbances of the system which cause the emission of light waves.

If the electrons which emit radiation revolve in orbits about the atoms, as indicated by the Zeeman effect, the nuclei of the atoms must be positively charged in order to hold the electrons in their orbits; and if the emission centers are as a whole positively charged, one electron or more must have been completely detached from the system, while the radiation is due to those left behind. In order that these orbits may be stable, we must, in the light of our present knowledge, assume one of two hypotheses—the electrons must either be held in equilibrium at a definite distance from the center by some sort of elastic force which it is difficult to account for, or the velocities of the electrons and the radii of their orbits must be so adjusted that there exists an exact balance between the centripetal and centrifugal tendencies, such as that which prevails in the solar system. But if the electrons radiate they must lose energy, and if they lose energy they might be expected to fall into the nuclei as the moon would fall into the earth if it continuously lost kinetic energy. Either hypothesis involves difficulties. J. J. Thomson elaborated the idea that the atom is a sphere of uniformly distributed positive electricity, in which electrons are imbedded in such fashion as to be subject to quasi-elastic (but really electric) forces which cause them to vibrate when displaced. Opposed to this there is the Rutherford atom. The weight of experimental evidence, chiefly radioactive, seems to favor the latter. The alpha particles of radioactive substance, which after their positive charges are neutralized become atoms of helium, have an atomic weight four times that of hydrogen. They are projected from their parent atoms with tremendous velocities, and in their progress through air at ordinary pressures ionize from sixty to one hundred thousand molecules, producing twice as many ions, and yet they travel in almost perfectly straight lines, and only at the end of their path, where their velocity has been greatly reduced, do they show any marked evidence of deflection or reflection by impact with mole-

cules. The molecules of nitrogen and oxygen are about eight times as heavy as the alpha particles, and it is evident that if the latter struck these molecules squarely, as they must do to produce ionization of the Thomson molecule, they would be scattered in all directions. Such would not be the case with the Rutherford atom or molecule. In general the alpha particles go unimpeded through the open structure, usually missing the very small positive nucleus, but occasionally producing ionization by detaching electrons near which they pass. On rare occasions an alpha particle will go so close to the nucleus as to be subjected to a strong deflecting force, as in the case of a comet passing through the solar system and getting near the sun, only in the latter case the force would be attractive, while the positive nucleus will repel the positive alpha particle. These effects are shown clearly in photographs taken by C. T. R. Wilson of the path of alpha particles in air, the tracks being made visible by the trail of fog particles due to condensation of water vapor on the ions. Rutherford obtained further proof in favor of his hypothesis by measuring the angles of scattering of alpha particles passing through thin films of metals. In this case the scattering is greater than in air, because of the greater number of atoms encountered in a given distance and their greater mass. The relative number scattered at different angles can be exactly calculated on the assumption of a definite number of elementary positive charges concentrated in the nuclei of the atoms. The results show very conclusively that the number of these elementary charges, or more properly the excess of positive over negative charges, does not exceed half the atomic weight, the number growing relatively less with increased atomic weight—for example, as indicated in these and other experiments, the excess of positive charges in the nucleus of calcium, of atomic weight 40, is 20; in that of gold, of atomic weight 197, the number is 79. Space does not permit giving in detail the mass of evidence supporting this remarkable conclusion, but it seems convincing, and has already formed the basis of a new chemistry, in which the atomic number (the excess of positive charges in the nucleus) takes the place of atomic weight as the significant factor determining the chemical properties of the substance.

If we accept the Rutherford atom, it seems necessary to eliminate quasi-elastic forces and to assume that equilibrium of the electrons which must associate themselves with the nuclei to form neutral atoms is maintained solely by rotation in cir-

cular or elliptic orbits. The existence of a large number of electrons moving in such orbits increases the difficulty of accounting for equilibrium, particularly when we consider losses of energy by radiation, which should result in constant readjustments. Further, if uniform rotation is accompanied by radiation (as we might expect from electromagnetic theory) the atom should constantly radiate. Atoms do not normally radiate, however, but only when subjected to a violent disturbance which temporarily upsets equilibrium. We can readily account for three definite frequencies accompanying such perturbations of a single electron. Superimposed on the circular motion there might be vibrations radial, tangential, and normal to the orbit, and if uranium, for example, of atomic number 92, has 92 such electrons circulating about it we could account for 276 spectral lines in this way. As a matter of fact, uranium has many thousand lines in its spectrum, and it seems beyond the powers of the human mind, with our present knowledge, to imagine the atomic structure which would account for the observed facts and emit radiation in accord with the accepted laws of physics.

Bohr has formulated a hypothesis applicable to the spectra of hydrogen and helium in which he boldly departs from some of these laws. He accepts the Rutherford atom, and assumes that hydrogen has a simple nucleus of one positive charge about which a single electron revolves. According to accepted laws, which associate radiation of waves with accelerated motion of electric charges, the electron revolving in a circular orbit should emit waves, for it is subject to centripetal acceleration. Bohr assumes that this law does not apply within the atom, although the ordinary laws of electrical attraction hold the electrons in their orbits. A further radical assumption is that there are a number of possible "stationary" orbits, of different radii, in each of which the electron may move under conditions of equilibrium. An external disturbance may cause the electron to jump from one orbit to another, and during this transition radiation is emitted amounting to one of Planck's energy quanta, that is the difference between the kinetic energies of the electron in the two orbits is radiated with a frequency which is determined by the relation that the frequency multiplied by Planck's "wirkungsquantum," the mysterious constant h, is equal to this energy. There must be as many possible orbits as there are lines in a series. Bohr deduced an expression for the frequencies of the principal lines of hydrogen like Balmer's

empirical formula, which had been known for some time, and which expresses with great accuracy the positions of the lines in several series including the principal lines of hydrogen. With equal success Bohr applied his hypothesis to the case of helium, with two nuclear charges and two detachable electrons, one of the latter being detached, but he could not solve the problem in the case when both electrons are retained. The problem for other atoms is likewise too difficult to solve.

Some years ago Laue showed that the X-rays are diffracted in passing through the regular space lattice of atoms in a crystal, producing diffraction patterns on a photographic plate similar to those observed in looking at a distant light through a fine-meshed handkerchief. This proved that the X-rays are due to waves. The Braggs showed that these waves could be reflected from the atomic planes in crystals, and Moseley, by an ingenious application of this principle, was able to determine the lengths of the stronger characteristic waves emitted by different metallic targets when bombarded by cathode rays. He discovered the remarkable fact that the square roots of the frequencies of the principal lines are proportional to the ordinal numbers, increasing by unity in passing from one element to the one of next highest atomic weight. Siegbahn has extended Moseley's results to the heaviest element, uranium, with atomic number 92, and downward to sodium, of atomic number 11. The known elements of smaller atomic weight fill the remaining places down to hydrogen, of atomic number 1, and there are but six gaps in the entire series, to be filled by possible discoveries of new elements. These results are consistent with the numbers referring to nuclear charges determined by Rutherford and others. Bohr's theory likewise leads to the conclusion that the square roots of the frequencies should be proportional to the nuclear charges. Any single line of evidence suggesting these relations might be regarded as highly hypothetical, but the cumulative effect of several kinds of diverse experimental evidence is to produce a feeling of confidence amounting almost to certainty that the nuclear theory is correct, although there is still uncertainty as to the relations of the radiating electrons to the nuclei. If the frequencies of vibration of the electrons are proportional to their frequencies of rotation, which seems highly probable, the extraordinarily high frequencies of the X-rays, several thousand times greater than those of ordinary light, indicates that the emitting electrons lie in orbits very close to the nucleus and practically forming a part of it, which

are excited to radiation by displacements due to intense electron bombardment, while the electrons emitting ordinary light, in numbers sufficient to neutralize the charge of the atom as a whole, lie in orbits of relatively large radius. In both cases, if Bohr's hypothesis is correct, there are a number of possible orbits for each electron, and radiation is emitted only in passing from one to another. This hypothesis fits the cases of several groups of lines in the spectra of hydrogen and helium with astonishing accuracy, yet it leaves much to be explained and involves the acceptance of notions which, to say the least, are difficult to reconcile with principles which have seemed to us to be firmly established. In the case of such a simple structure as that assumed for hydrogen, how can we account for the number of stationary orbits demanded? What determines the frequency of the radiation emitted when an electron passes from one orbit to another? It would seem to be necessary for the electron to know in advance what orbit it will finally adopt. How shall we account for the thousands of other lines in the spectrum of hydrogen which the hypothesis fails to account for, and for the continuous spectrum? These things seem to demand a greater complexity than that assumed by Bohr. Stark has lately found that the spectral lines of hydrogen and of a few other elements are split up into many components when the radiating gas is in a strong electric field, in such a way as to strengthen the suspicion that more than one electron takes part in the radiation. It does not seem impossible that the nuclei of both hydrogen and helium may be built up of smaller positive units than the alpha particle and the assumed simple hydrogen unit, with electrons combined with them, so that the resultant nuclear charges are respectively 1 and 2. So far, however, there is no experimental evidence pointing to the existence of a smaller positive electron than the hydrogen nucleus.

There is another possibility which can not be overlooked, although there is little experimental basis for any clear-cut hypothesis—a static atom, that is, one in which the electrons are normally at rest in a condition of static equilibrium, held in place by quasi-elastic forces which set up vibrations when the electron is slightly displaced. Such an atom would probably better suit the chemist than the Rutherford atom, for how can we imagine two atoms in which the outer rings of electrons, the "valency" electrons, are in rapid rotation, ever entering into permanent relations with each other in the molecular state?

But we are unable to account for such quasi-elastic forces in the open structure demanded by radioactive phenomena, and it is impossible to imagine electrons stationary in space, with nothing to hold them apart from the neighboring attracting positive charges.

It is evident that we have far to go to reach a complete explanation of light emission, but the experimental developments of the past few years, the circumstantial evidence based on many different lines of attack, give us reason to hope that we may solve the problem qualitatively at least, that is, decide definitely between the Rutherford and the static atom, and possibly in the simpler cases, such as that of hydrogen, arrive at a fairly complete solution of the problem. A complete quantitative solution of the general problem we can hardly expect. The astronomer can not solve the problem of three bodies in such a system as that of our sun; how can we expect to solve the far more difficult problem of the motions of the swarm of mutually attracting and repelling particles in the atom?